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PHYSIOLOGICAL EFFECTS OF NAACH VOLTAGES

Frank H. Jacobson
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NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

1 JULY 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Measurements of voltage drops between electrodes inserted into the skull and neck musculature of cats demonstrate that NAACH passes audiofrequency current through the body. Evidence was obtained that the magnitude of this current could vary, but the limits of variability have not been determined. Within the range that occurred in daily exposures over a period of 17 days, no consistent effect on sleep or alertness was observed. No significant changes were detected in one electrocardiogram channel or in any other physiological parameter.

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SUMMARY

INTRODUCTION

The NAACH (non-acoustic audio coupling to the head) "earphone" was developed to remedy a deficiency in Navy communications in noisy environments, especially helicopters. It is said to perform where other types fail completely. Furthermore, its bulk is so small that its incorporation into helmets in place of conventional earphones would result in a perceivable reduction in weight. However, the very high voltages used in the system pose the possibility of hazards to normal function and performance of the wearer. Therefore, investigation of these hazards was assigned under AIRTASK No. A310310C/001A/WR0410101.

SUMMARY OF RESULTS

No evidence of d.c. flow between, or of generation around NAACH electrodes has been observed. In acute experiments, constant (for several minutes) audio signal voltages as high as 750 volts (rms) biased by d.c. voltages as high as 900 volts were applied. The measured integral of the total rectified electrical activity of the trapezius muscle increased with each increase in the voltage of the audio signal applied to the NAACH electrodes. It was demonstrated that this increase in the integral was accompanied by increased af (audiofrequency) current passing through the head and being picked up by the muscle electrodes or their connections to the Winchester plug mounted on the head. It was also demonstrated that the muscle was sometimes less active when the af current was flowing and probably was not being stimulated.

One cat was exposed to 4-hour daily NAACH receptions of a 3-kHz signal at the above voltages 4 days a week for 4 weeks. On the fifth day of each week, this cat exhibited a small increase in QS (spindle and slow-wave sleep), but not in AS (rapid-eye-movement sleep). Three other cats received NAACH-transmitted speech daily except on days 7, 12, and 17. (The speech signal voltage fluctuated continuously between nearly 0 and 1000 volts with a mode of ca. 400 volts, and was biased by 1020 volts d.c.) The same cats also listened to acoustical speech for the same number of days, either before or after the NAACH exposures. No consistent difference in sleep time or stages occurred as a result of NAACH exposure.

A single-channel EKG (electrocardiogram) was recorded in six cats during presurgical anesthesia and during surgical-level anesthesia after 6 to 14 days exposure to NAACH voltages. The differences were not clinically significant, according to a veterinary cardiologist, although one cat did develop a sinus tachycardia.

CONCLUSIONS AND RECOMMENDATIONS

No impairment of alertness or disturbance of sleep that would preclude exposing human subjects to NAACH voltages was discerned. Assured safety requires, however, that current flow through the subject's body be no greater than it was during the sleep studies. Unfortunately, the units furnished for this investigation lacked current-monitoring capability, and no assurance exists that the

current flow measured on one occasion remained constant and might not at some time reach unacceptable levels, such as are said to have been measured in other units.

It is recommended, therefore, that the range of current flow through the heads of the cats be assessed before human tests are begun.

A causal effect between exposure to NAACH voltages and the tachycardia developed by one cat has not been demonstrated. Nevertheless, it is recommended that pulse rates be counted during each exposure of human subjects, and that clinical EKG's be recorded at least weekly. A safer, and therefore preferable procedure would be to compare pre- and post-exposure EKG's in cats using multiple leads without the masking effect of anesthesia, before human tests are begun.

It is further recommended that human tests include measures of subjects' decision-making efficiency, sense of equilibrium and orientation, and ability to concentrate.

ACKNOWLEDGEMENTS

Funds for this work were provided by the Naval Air Systems Command (AIR-310C, and from AIR-340B through the Life Support Branch, Crew Systems Engineering Division, Crew Systems Department).

Grateful acknowledgement is made of the invaluable assistance of the following personnel: Mr. Samuel Greco, for construction of the NAACH unit used in acute experiments, and for electronic technical assistance; HMC J. W. MacCoy, for surgical preparation of the acute animals; Mr. W. P. Orrick, for technical assistance and counsel in design of experiments; Mr. S. Krieg, for design of the electrodes, supervision of the construction of the NAACH units, loan of accessory equipment used in the chronic experiments, and for counsel in electrical circuit problems; Mr. G. E. Bergey, for advice in circuit problems; Dr. M. M. Cohen, for advice on electromyographic technique and human performance testing; Dr. C. W. Lombard, for analysis of the electrocardiograms; Dr. R. J. Kolata, for veterinary consultation; Dr. L. G. Best, for screening the cats for normal hearing; TD1 R. Reinwald, for electronic technical assistance; and HM3 E. Lane and HN J. Ethridge, for surgical assistance.

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INTRODUCTION

The ambient noise in helicopters and other aircraft makes communications difficult, and sometimes impossible. Efforts to remedy this situation have led to the development of a new type of "earphone" that functions effectively in airborne noise fields, and is so small in bulk that it can be incorporated into helmets. The earphone consists of an insulated metal disc contacting the head, but not covering the ear. Because it does not couple with airborne noise, which can be blocked out by earplugs, this earphone performs where other types fail completely. The transducer has been given the name "Non-Acoustic Audio Coupling to the Head," or "NAACH," to emphasize this feature.

The insulated NAACH electrode is thought to operate as a capacitor earphone, in which skin serves as the diaphragm[1]. An audio signal voltage carried on a d.c. bias to the electrode causes the skin to vibrate. Presumably, the skin vibrations are somehow transmitted to the cochlea where they are transduced into nerve impulses.

Signal voltages used in prototypes have approached 1000 volts (rms), and d.c. biases employed have reached 1500 volts. Theoretically, a.c. (alternating current) increasing with frequency could be expected to flow across the condenser formed by the insulated NAACH electrode pressed against the skin. Indeed, af (audiofrequency) currents in the mA (milliampere) range have been measured in the electrode leads, according to undocumented reports, and presumably, although not necessarily, have flowed through the head. Direct evidence that this current does flow through the head has been obtained by us, although its magnitude has not yet been determined. More pertinent than the magnitude of current was the question of whether structure and chemistry of the brain were being damaged, as indicated by alteration of physiological function.

The formation of Ach (acetylcholine), which is an important neurotransmitter in the sleep and arousal systems, as well as other systems of the brain, is a function which might be altered. Noval, et al.,[2] have reported that CAT (choline acetyl transferase) activity was significantly lower (16 to 18 percent) in the brain stems of rats which had been exposed continuously for 30 days to low-voltage 45-Hz fields than in the brain stems of unexposed rats. Conceivably, reduced CAT activity and, presumably, reduced Ach formation might have caused the cortical desynchronization and behavioral excitation in sedated rabbits observed by Goldstein[3], following 5-minute exposures to microwave fields. Both the cortical desynchronization and behavioral excitation could have been due

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[1]Salmansohn, M.; Non-Acoustic Audio Coupling to the Head (NAACH); NAVAIRDEVCEN Rept No. NADC-AE-6922; 1969.

[2]Noval, J.J., Sohlen, Arthur, Reisberg, R.B., Coyne, Harold, and McKinney, Hubert; Biochemical Effects in Rats Exposed to Extremely Low-Frequency (ELF), Non-Ionizing Radiations; Proc. Ann. Mtg Amer. Soc. Neurochem.; 1974.

[3]Goldstein, Leonide; Final Report on NAVAIRDEVCEN Contract No. N62269-72-C-0116 with Office of Naval Research; 1972.

to reduced Ach formation in the bulbar reticular formation[4], the nucleus centralis medialis[5], the caudate nucleus[6], and/or along the inhibitory pathway traced caudad from the preoptic region by Hernandex-Peon, et al.[7] The introduction of Ach or cholinomimetics into these sites has been reported to induce sleep (but not specifically active sleep alone) in experimental animals. On the other hand, reduced Ach formation in the ventral tegmentum and adjacent substantia nigra or the nucleus cuneiformis could be expected to result in sleepiness, inasmuch as they are the origins of the cholinergic tegmental pathways described by Shute and Lewis[8] as "constituting the anatomical basis of the ascending reticular activating system of physiologists."

In a preliminary experiment in which one cat was exposed to a NAACH-transmitted 3-kHz note 4 hours a day for 4 days a week for 4 weeks, it was monitored on the fifth day of each week for sleep and alertness. This cat exhibited a small increase in time spent in quiet (spindle and slow wave) sleep without increase in active (rapid-eye-movement) sleep. Therefore, a series of six cats was prepared to determine whether this increase in QS (quiet sleep) could be considered statistically significant.

Theoretically, a fluctuating magnetic field is generated around the NAACH condenser. Therefore, the induction of a direct current in this field cannot be excluded, although it has not been measured. Severe labyrinthine symptoms (false sensations of rotation, nystagmus, vertigo, nausea, vomiting, even falling) can be evoked in 9 percent of the human population by currents of 0.1 to 1.0 mA flowing between uninsulated electrodes near the ears; and in an additional 39 percent by currents of 1 to 2 mA[9]. Since the NAACH d.c. voltages

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[4] Cordeau, J.P., Moreau, A., Beaulnes, A., and Laurin, C.; EEG and Behavioral Changes Following Microinjections of Acetylcholine and Adrenaline in the Brain Stem of Cats; Arch. Ital. de Biol. 101, pp 30-47; 1963.

[5] Yamaguchi, Nariyoshi, Ling, G.M., and Marczynski, T.J.; The Effects of Chemical Stimulation of the Preoptic Region, Nucleus Centralis Medialis, or Brain Stem Reticular Formation With Regard to Sleep and Wakefulness; Recent Advances in Biol. Psychiat. 6, pp 9-20; 1964.

[6] Stevens, J.R., Kim, Chul, and MacLean, P.D.; Stimulation of Caudate Nucleus; Arch. Neurol., Chicago. 4, pp 59-66; 1961.

[7] Hernandez-Peon, R., Chavez-Ibarra, G., Morgane, P.J., and Timo-Taria, C.; Limbic Cholinergic Pathways Involved in Sleep and Emotional Behavior; Exp. Neurol. 8, pp 93-111; 1963.

[8] Shute, C.C.D., and Lewis, P.R.; The Ascending Cholinergic Reticular System: Neocortical, Olfactory and Subcortical Projections; Brain. XC, pp 497-521; 1967.

[9] Camis, Mario; The Physiology of the Vestibular Apparatus (Translated and Annotated by R.S. Creed); Oxford, Clarendon Press, pp 209-212; 1930.

are applied through a minimal resistance of 10 megohms*, d.c. current would exceed 0.1 mA only in case of breakdown of the electrode insulation. However, it is conceivable that the much smaller currents leaking through the insulation, and/or the electromagnetic forces acting upon the labyrinths for long periods of time could produce pilot disorientation perceptible only as angular illusion and error in adjusting plane attitude.

Before testing for such subtle effects on human subjects, we have been looking for grosser effects on cats which might make the tests unsafe for humans.

METHODS

ACUTE STUDIES

The experimental animals (cats) were trained to rest quietly in a "rabbit box" (figure 1). Sensors for the ECoG (electrocorticogram), EOG (electro-oculogram), and nuchal EMG (electromyogram) were implanted under pentobarbital anesthesia (30 to 35 mg/kg) a minimum of 2 weeks before the first experiment. Stainless steel sheetmetal screws turned into the skull overlying the auditory cortex served as differential electrodes for the ECoG. The EOG was recorded differentially from a screw in the infraorbital process of each zygomatic arch. Two stainless steel wire loops sewed with steel sutures to one trapezius muscle were electrodes for the EMG.

From each pair of sensors, stainless steel wires ran under the skin to a 7-pin female plug mounted on the skull in dental cement (figure 2). Male plugs inserted at the beginning of the experiment were connected to cables leading to the Dynograph for direct writeout. The ECoG was led off from a post-amplifier to an analog computer, which separated the brain waves into five frequency bands and wrote out a running average of the wave amplitudes in each band. Center frequencies of the bands were 2.2, 5.5, 10.0, 17.5, and 30.5 Hz. The EMG was also led off from a post-amplifier to an integrator. The integral was then recorded simultaneously on another channel of the Dynograph.

The inflow and outflow of air during respiration were indicated in some experiments by changes in the temperature of a copper-constantan thermocouple. Michel suture clamps inserted into the skin on either side of the thorax served as electrodes for the EKG in acute experiments. A third screw turned into the roof of a frontal sinus served as a common ground for all measurements.

Two cats were exposed to d.c. current through uninsulated stainless steel discs (1-cm diameter) taped over electrode paste at the bases of the tragi. These cats were exposed further to a low-voltage (0 to 37 volts (rms) af; 220 volts d.c.) NAACH system, described in detail by Salmansohn[1]. A third

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* In the units furnished for the chronic experiments, 1020 volts d.c. was applied through 132 megohms.

[1] See page 5.

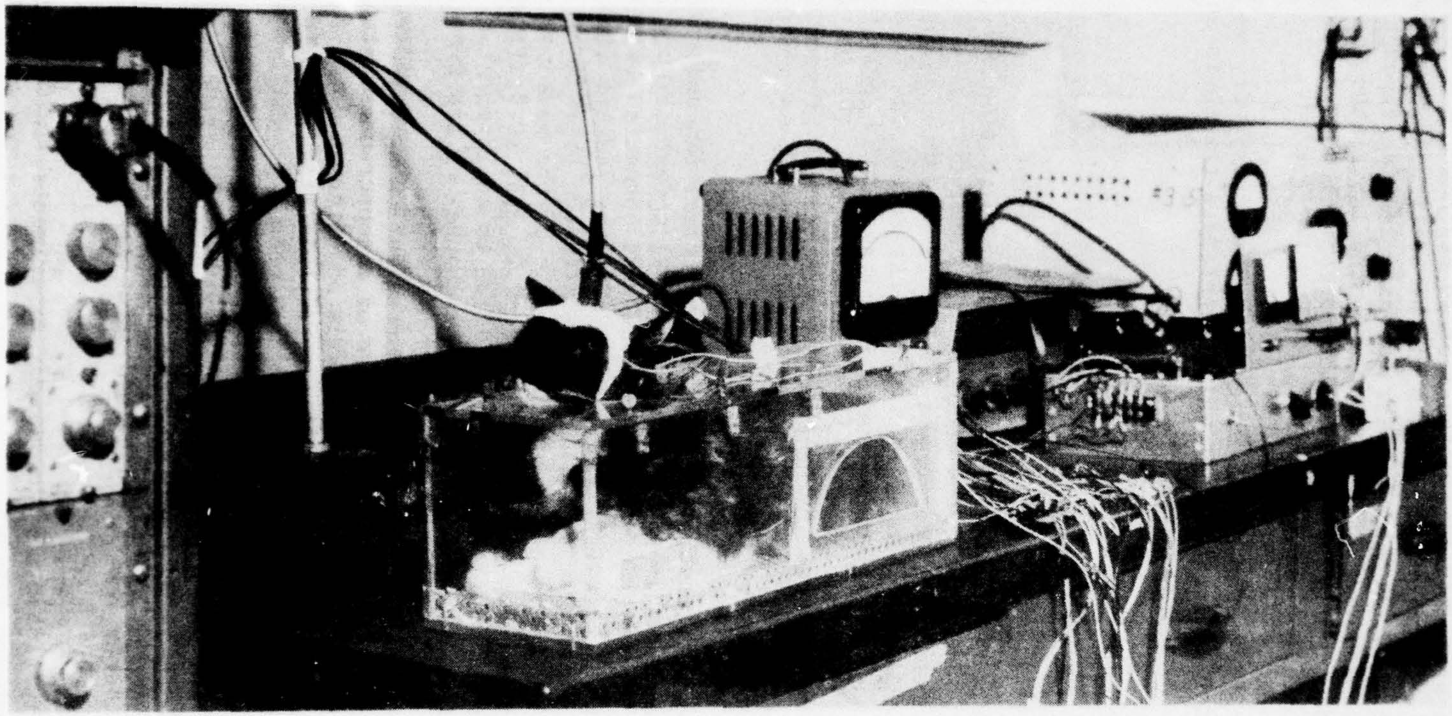

Figure 1. Cat Receiving NAACH-Transmitted Sound in Acute Experiment. (The cable from the cat's head to the terminal strip on the table is plugged into a 7-pin female plug mounted on the cat's skull. To the right are components of a laboratory version of the NAACH system. The NAACH electrodes are taped to the cat's head. To the left is the Dynograph.)

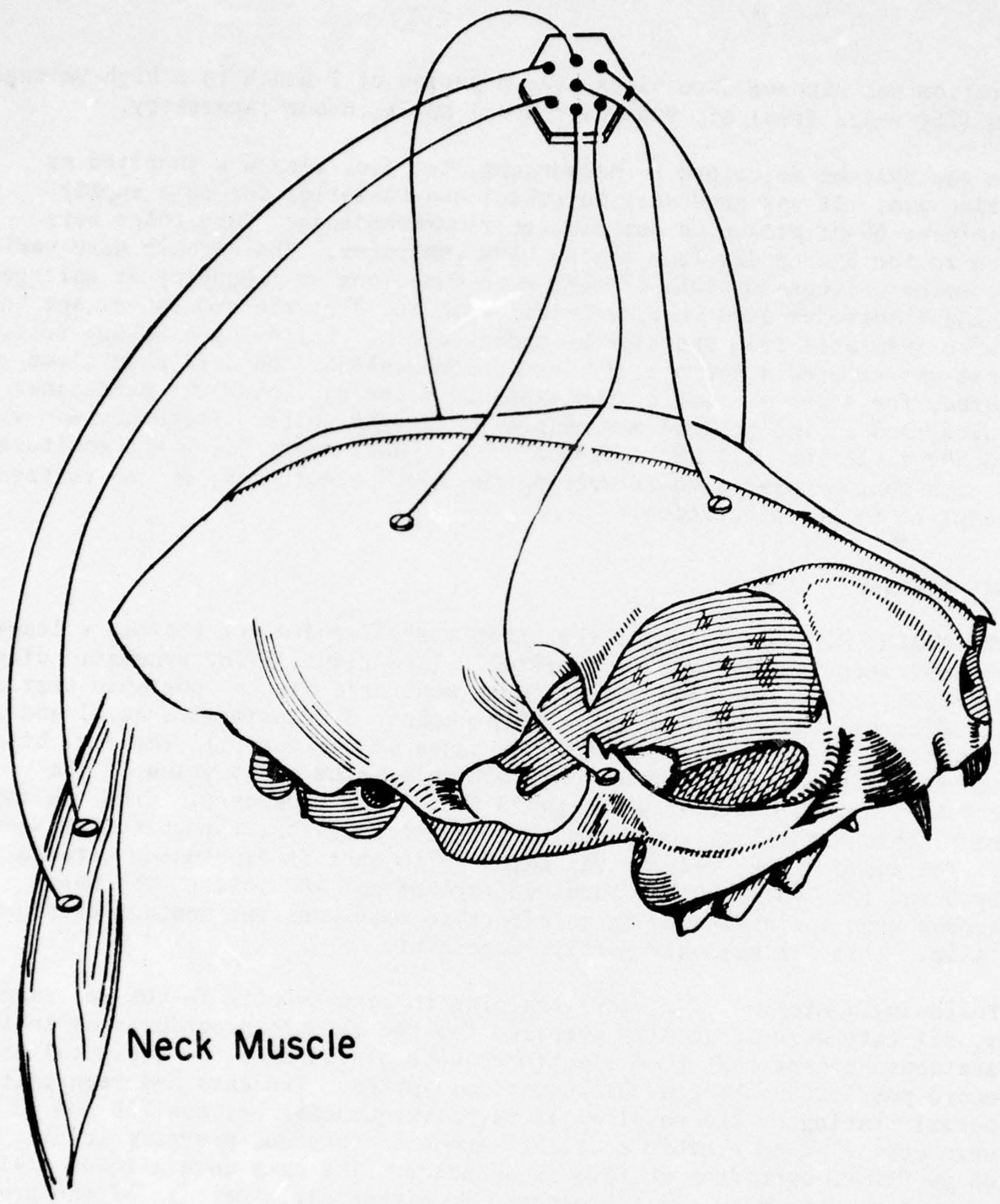

Figure 2. Cat Skull Showing Three Pairs of Electrodes and the Common "Ground" Electrode in the Roof of a Frontal Sinus. (The muscle electrodes were stainless steel loops sutured to the muscle with stainless suture wire. The 7-pin female plug to which the electrodes were connected was mounted on the skull in dental cement. The ECoG electrodes are shown over the auditory cortex as they were in the acute studies. In the chronic studies, they were located over the occipital cortex.)

preparation was exposed five times over a period of 1 month to a high-voltage system (750 volts (rms) af; 900 volts d.c.) built in our laboratory.

In the systems described by Salmansohn, the d.c. bias was supplied as rectified a.c. It was necessary to substitute batteries for this supply to eliminate 60-Hz pickup in our bioelectric recordings. Pure tones were applied to the electrodes from a sine wave generator. The signals were varied to determine whether possible effects were functions of frequency or voltage. The NAACH electrodes used were identical with the d.c. electrodes, except that they were insulated from the skin by a dielectric. Following a 38-day rest, this cat was exposed 4 hours a day, except on weekends and days when sleep was monitored, for 4 weeks. During the exposures, the d.c. bias was maintained at 900 volts, and af rms voltage was maintained at 750 volts. Frequency was varied from 3 kHz to 10 kHz at 1 kHz increments every half hour. Sleep was monitored after each four exposures while wearing the NAACH electrodes, but no voltages were applied to the electrodes.

CHRONIC STUDIES

The NAACH units supplied for the chronic studies did not contain voltage- and current-metering devices as requested. (See figure 3 for schematic diagram of NAACH unit.) However, af voltages were monitored with a portable test meter connected across the secondary coil of the combined transformers at J1 and J2. (No correction was made for frequency response of the meter.) The d.c. bias voltage was assumed to be constant at 1020 volts, the rated value of the batteries. The audio signal was a taped radio news broadcast. From the tape recorder, this signal was conducted to a stereoamplifier, thence to the NAACH unit. The audio signal voltage was adjusted so that it fluctuated between nearly 0 and 1000 volts with a modal voltage of ca. 400 volts. The NAACH electrodes were spring-loaded in an effort to make constant contact pressure with skin. This aim was only partly successful.

Following a minimum of 2 weeks training to rest quietly in the restraint boxes, six cats were surgically prepared for the chronic procedures as in acute preparations, except that ECoG electrodes were placed over the occipital cortex to record possible ponto-geniculo-occipital spikes. The cats had been tested for normal hearing by the supplier at seven frequencies between 250 and 12 kHz, and were certified to exhibit cortical responses to sound-pressure levels of +30 dB re 0.0002 dynes/cm^2 at five frequencies. The cats were allowed a +10-dB variance at no more than two frequencies in either ear. Details of the procedure are elaborated by Teter[10].

During presurgical anesthesia, so it would not contain movement artifacts, an EKG was recorded between needle electrodes over the apex of the heart and

[10] Teter, D.L.; A Comparison of Summed Cortical Evoked Responses and Avoidance Conditioned Responses to Pure Tones in Cats; unpublished doctoral dissertation, University of Denver, pp 53-55, 57-62; 1969.

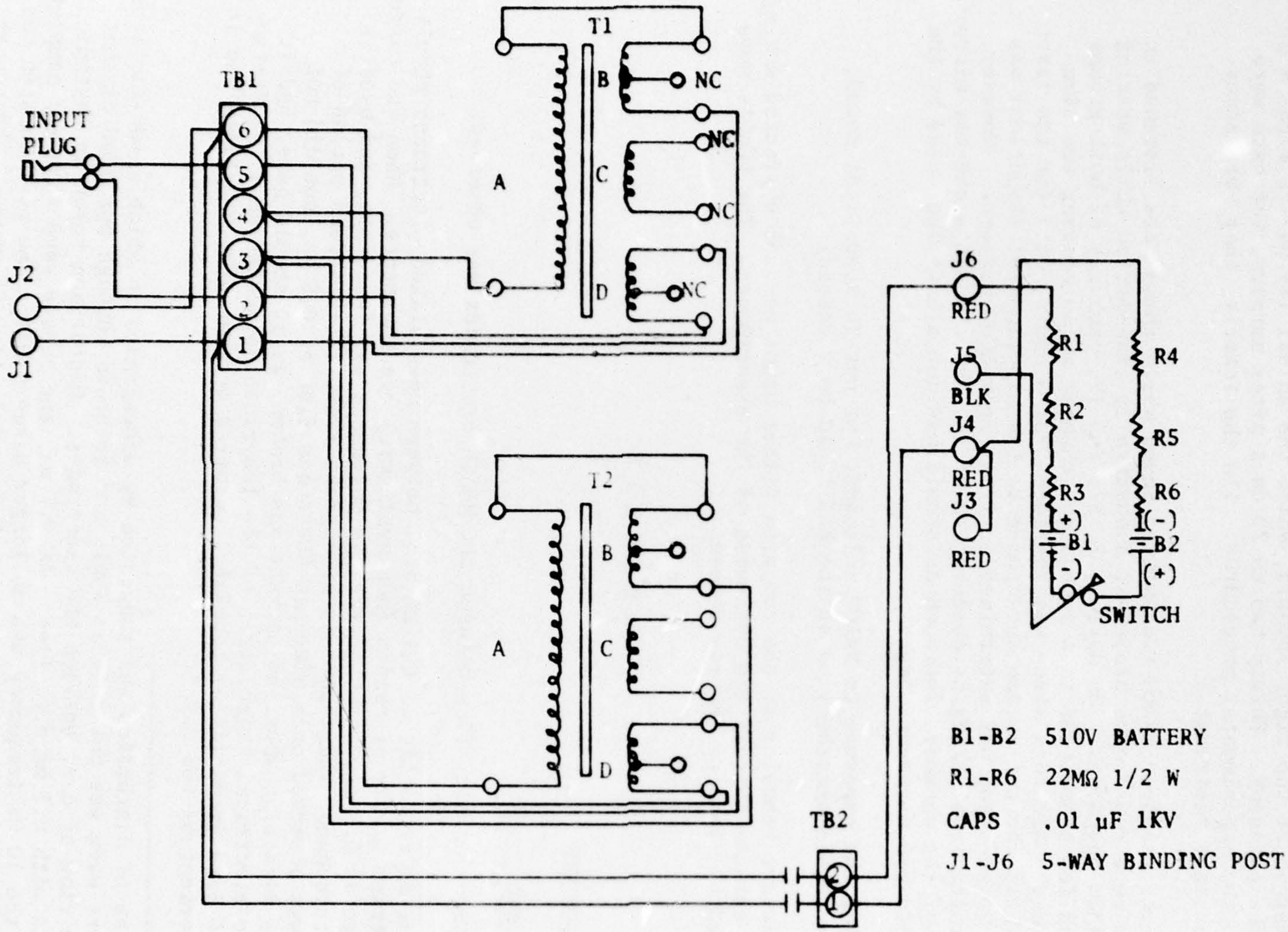

Figure 3. Schematic of the NAACH Unit Used in the Chronic Studies.
(Note that $T1_D$ and $T2_D$ are connected in series to serve as the primary turns, and $T1_A$, $T1_B$, $T2_A$, and $T2_B$ are connected in series to serve as the secondary turns of the transformer combination. J1 and J2 are connections for measuring the voltage across the secondary. The "earphones" were connected to J6 and J4.)

the dorsal margin of the right scapula, while the animal lay on its right side with all limbs extended. Thirty-two to 70 days after surgery, the cats were subjected to the experimental procedures. (In the interim, they were accustomed to the light restraint.)

Three cats received NAACH-transmitted sound while three cats listened in another room to a radio news broadcast acoustically transmitted while wearing simulated NAACH earphones. On days 1, 7, 12, and 17, each cat of both groups was monitored for sleep time in a soundproof chamber while wearing the simulated earphones. Although sleep was monitored for 3 hours, data for the first half hour (while the cat became accustomed to the experimental situation) was discarded. Quiet sleep was determined entirely from ECoG patterns. However, AS was separated from waking by observation of the cat through a one-way mirror in a window of the chamber, inasmuch as atonia was not always indicated by the EMG when rapid-eye movements began.

Following the exposure to NAACH voltages, but not to acoustical sound, the cats were again anesthetized so the EKG could be recorded.

Intermittent behavior of the computer filter bands was not corrected during the interim between surgery and beginning of the experiments. The ECoG's were then analyzed by scanning the raw records.

R E S U L T S

ACUTE EXPERIMENTS

Direct Current

No evidence of d.c. flow between the NAACH electrodes was observed.

The flow of as little as 0.1 mA d.c. between uninsulated electrodes resulted in intermittent bursts of random (non-nystagmic) eye movements. When the current was as large as 0.3 mA, onset of the eye movements was immediate, and usually persisted throughout short periods of current flow. (A 15-second period of nystagmus was observed once after an 80-second flow of 0.5 mA, but did not reverse its direction when the current was broken, as it should have, had it been due to electrical stimulation of the labyrinthine mechanism.) Distortion of the ECoG (and preamplifier blocking) occurred because of d.c. shifts due in part to movement of the cat *.

* One source of distortion was suggested by experiments in which a 100-microvolt 10-Hz square wave was put into an apple and recorded through our ECoG circuit during the flow of d.c. between the electrodes. Distortion began as rhythmical d.c. shifts with 0.1 mA d.c. flow. At 0.7 mA, the square wave form was completely lost, and the 10-Hz frequency was no longer discernible. The pattern seen was an irregular, fast wave riding on much larger 0.5 to 2-Hz waves. The square wave could be recovered by breaking the d.c., but, perhaps as a result of polarization of the apple tissue, the distortion by d.c. returned sooner and at lower d.c. values.

No distortion of the ECoG was observed during NAACH reception, even at 3 kHz. At lower frequencies, the ECoG was completely masked by the audiosignal or subharmonics. Eye movements were not stimulated by even 900 volts d.c. applied to the insulated NAACH electrodes.

Alternating Current

Audiofrequency flow in the milliampere range has been measured in the NAACH leads, according to undocumented reports. The suggestion of stimulation of the vestibular apparatus by af leaking across the insulation of the NAACH electrodes was eliminated by filtering out frequencies interfering with recording of the EOG. Then, no difference in the EOG could be observed during and before (or after) NAACH reception. Heart rate did not vary with voltage or frequency of the audio signal. The situation considered most likely to produce cardiac arrest was simulated on several occasions by placing large NAACH electrodes on opposite sides of the shaved thorax and applying 60 Hz at 400 volts (rms) while the EKG was being recorded. (60 Hz has been demonstrated to be the frequency most likely to cause ventricular fibrillation[11].) The EKG was masked during the 60-Hz flow, but fibrillation apparently did not occur, inasmuch as it was absent immediately after the 60 Hz was turned off.

Stimulation of neck muscles or of brain cells controlling the muscle activity was also suggested by increases in the integral of EMG activity of the trapezius muscle with increases in the voltage of a 3-kHz signal applied to the NAACH electrodes. The increases in the integral were sometimes associated in time with observable bursts in the "raw" EMG. However, the response of the recorder drops off sharply above 150 Hz, whereas the integrator integrates frequencies up to 5000 Hz. Therefore, many muscle action potentials were unrecorded, although integrated.

It is also possible that the muscle was not stimulated by the audio signal leaking through the insulation of the NAACH electrodes. Rather, it is possible the 3-kHz signal was picked up by the muscle electrodes, integrated and added to the integral of the muscle action potentials. An experiment was designed which indicated that this was the case: A wave analyzer was connected to the trapezius muscle of one cat by way of the Winchester plug mounted on the cat's skull. Successive sweeps of the spectrum from 20 to 950 Hz were made, alternating sweeps when the cat "listened" to a 775-Hz sine wave at 500 volts and when the NAACH was turned off. The output of the analyzer was graphed by an X-Y plotter with frequency in Hertz as the abscissa and microvolts as the ordinate. Figure 4 shows the electrical output of the muscle before (below) and during (above) NAACH reception. Note the presence of the 775-Hz signal in the upper plot. The greater electrical activity of the muscle seen here during NAACH reception was not a consistent finding. This is shown in figure 5, where less muscle activity was recorded during NAACH reception.

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[11] Wégria, René; Fibrillation: Ventricular; Medical Physics (edited by Otto Glasser), Vol 1; Chicago, Year Book Publishers, pp 442-446; 1944.

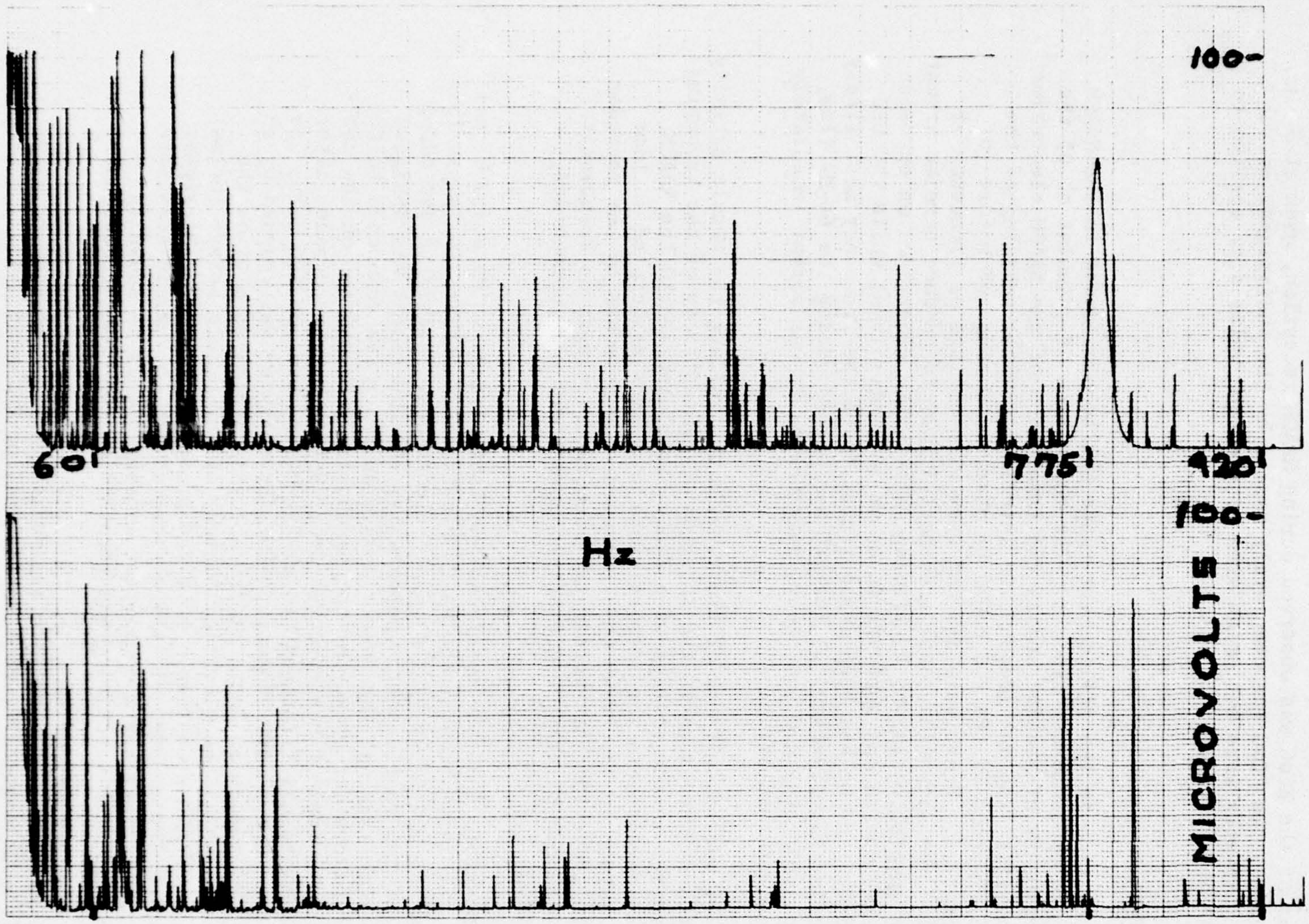

Figure 4. Spectral Sweeps of the Trapezius Muscle by a Wave Analyzer.
(In the upper record, the cat received a NAACH-transmitted 775-Hz sine wave, which was detected in the muscle. The abscissae are Hertz. The ordinates are microvolts. In the lower record, the 775-Hz sine wave was turned off. Peak readings of the analyzer below 20 Hz are instrumental artifacts.)

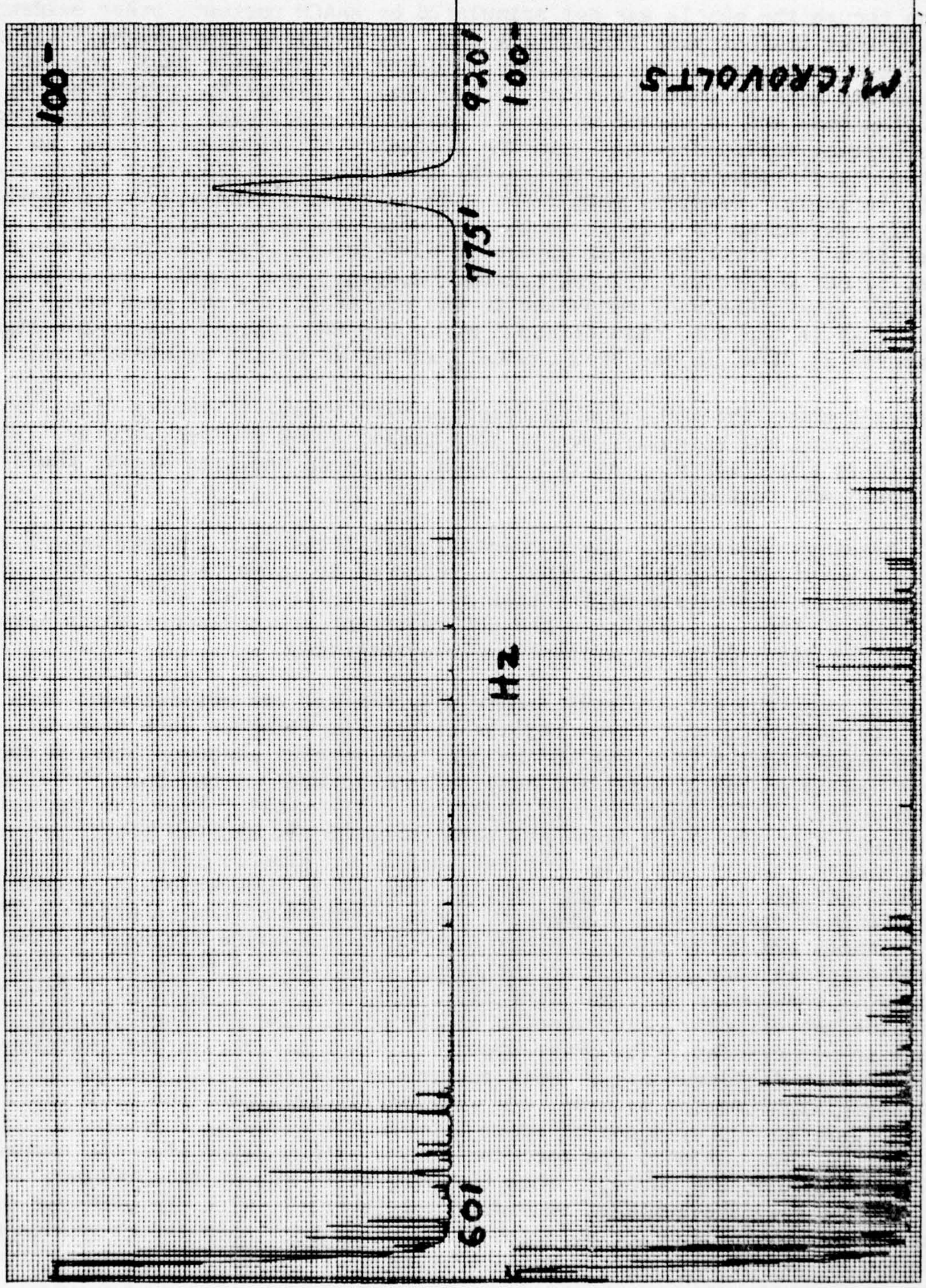

Figure 5. Additional Spectral Sweeps of the Trapezius Muscle Which Indicate that NAACH Current Passing Through the Muscle Did Not Stimulate Muscle Activity.

Even though the muscle was not stimulated by NAACH current, other evidence indicated that it does pass through the cat. By applying audio signals within the frequency response of the recorder, evidence was obtained that, when NAACH earphones are worn on opposite sides of the head, alternating current passes through the head and is picked up by all implanted electrodes. The magnitude of this current varies directly with the frequency of the audio signal, so that when mixed frequencies (as in speech) are being received, this current will be quite variable. However, when 37-Hz sine waves were received at 320 volts (rms), 37-Hz waves up to 0.75 mV in peak-to-peak amplitude (0.27 mV (rms)) were recorded from the three pairs of implanted electrodes. Waves of 1 kHz could not be recorded by our mechanical writing system. However, their amplitude could be measured by a wave analyzer connected to the electrodes by the same cable as 2.80 mV (rms) in the ECoG channel and 5 mV in the EMG channel. A 10-kHz signal was measured as 21 mV in the ECoG channel, and as 28 mV in the EMG channel.

Figure 6 shows the EOG and ECoG recorded with normal filtering (i.e., upper cutoff at 30 Hz) and slightly greater than normal speed and sensitivity. The EMG cutoff is above 150 Hz. At the vertical arrow on the time scale, the 37-Hz audio signal was turned on.

All tracings in figure 7 are completely unfiltered (i.e., upper cutoff above 150 Hz). Therefore, the audio signal is recorded as larger waves. (Note that the calibration sensitivity of the ECoG and EMG is less than half the sensitivity in figure 6.) The d.c. shifts in the EOG represent eye movements which were too large for the sensitivity at which they were recorded.

In figure 8, the audio signal received by the cat was not recorded when the pins of the male plug that connected the cat to the recorder were shorted (through resistances equivalent to the d.c. resistances measured between the pairs of implanted electrodes) and dangled approximately 1 cm above the female plug connected to the electrodes and mounted on the skull. Figure 9 shows the audio signal when the NAACH earphones were taped to the shorted plug. Apparently, the signal will record only when the unshielded plug or its connections to the electrodes lie in the path of current flow. This conclusion is supported by the evidence presented in figure 10, where portions of the record from the three channels are shown on a vertical time scale alongside diagrams of the plug and earphone configuration at the time. (Only one of the pair of parallel earphones is shown as a straight line at varying distances and angles from the pins inside the circular cross section of the plug. The pin configuration is the same in all circles. The chart speed is only 1 mm/sec, so the individual waves cannot be distinguished.) Near the top of the chart, it can be seen that the voltage inputs to the recorder are very nearly zero when the plug rests alongside, but outside the cylinder of space between the circular earphones. (No pick-up by the shielded cable to the recorder occurs either, even when the earphones are pressed against the cable.) When the plug rests inside this cylinder of space (figure 10), the voltages recorded vary inversely with the distance of the earphones from the plug. The voltages are also highest when the earphones are perpendicular to the axes of the pairs of pins of the plug.

Since the plug, the electrodes, and their connections lay entirely outside the cylinder of space between the earphones worn by the cat, there would have have been no pickup of the audio signal by the recorder if electrical current

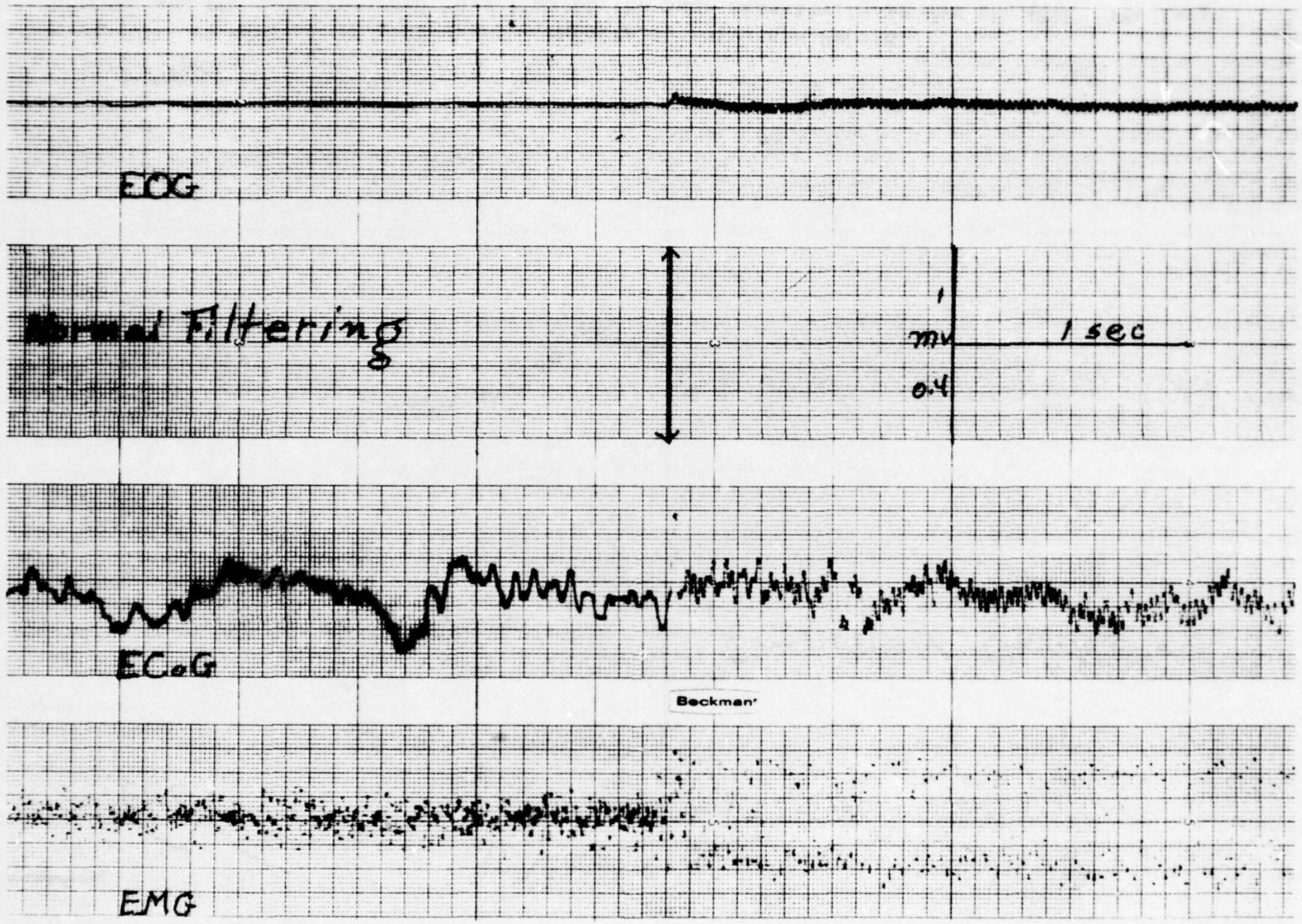

Figure 6. Polygraph Record of the EOG, ECoG, and EMG With Normal Filtering Before and After (at the Vertical Arrow) a NAACH-Transmitted 37-Hz Wave was Turned on. (Note that the ECoG and EMG are recorded on a more sensitive scale than the EOG. No eye movements occurred.)

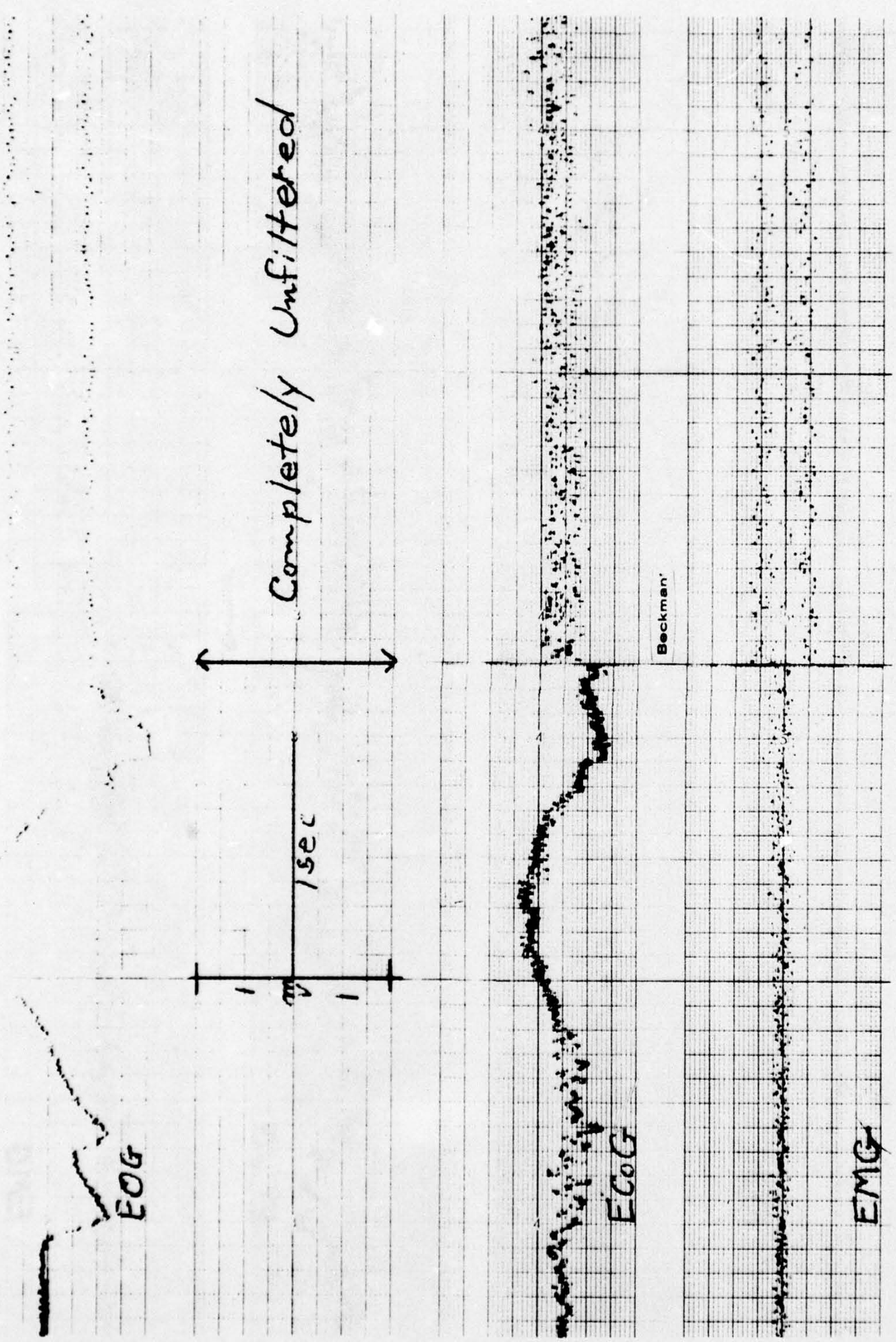

Figure 7. Unfiltered Polygraph Record.
(ECoG and EMG were recorded this time at the same sensitivity as was the EOG. The large d.c. shifts in the EOG record represent eye movements, which ordinarily are recorded with less sensitivity, so pen-blocking does not occur as it did in this record.)

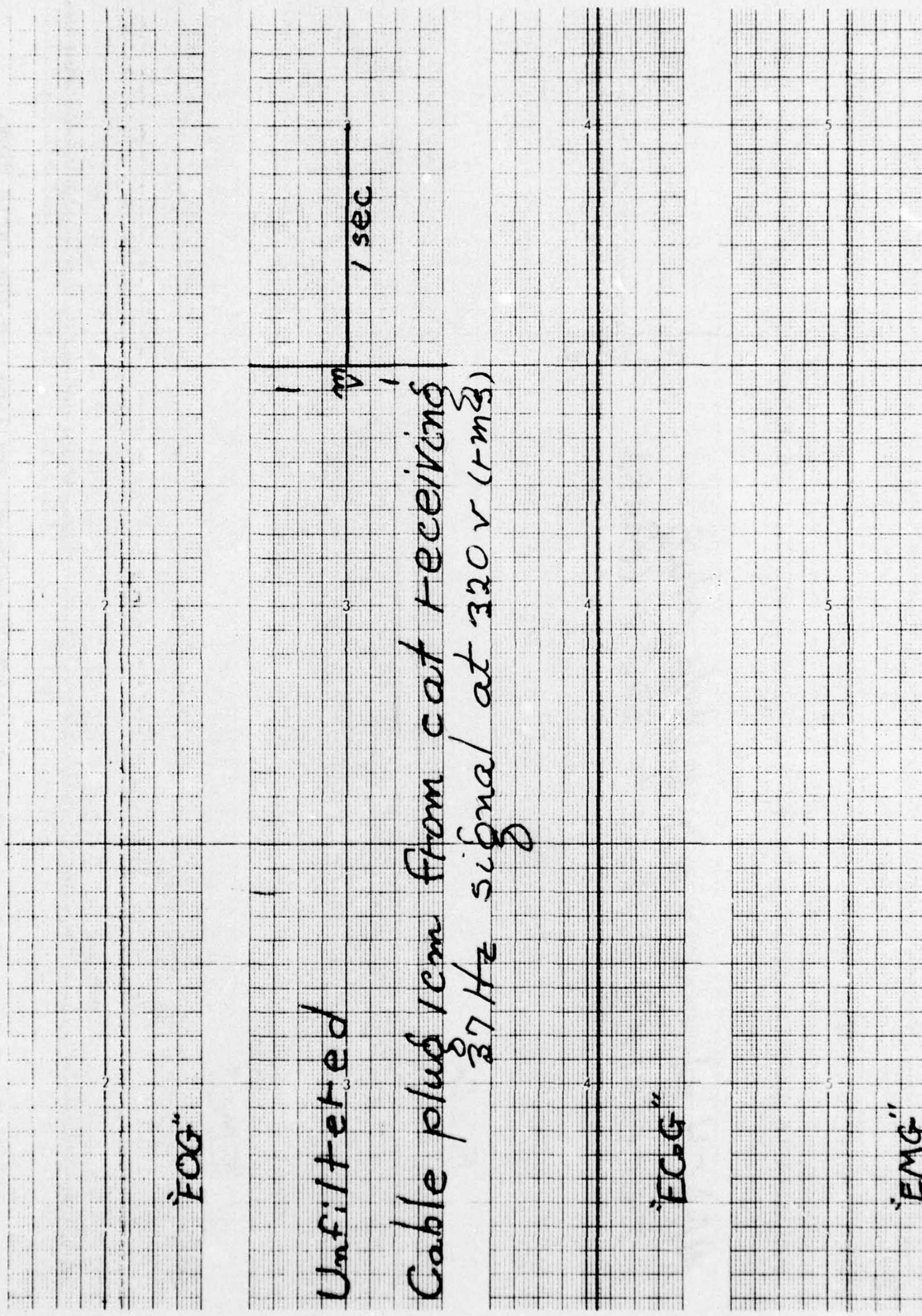

Figure 8. Unfiltered Polygraph Record With Shorted Cable Dangled 1 Centimeter Above the Plug Mounted on the Skull of a Cat Receiving a 37-Hz Signal.

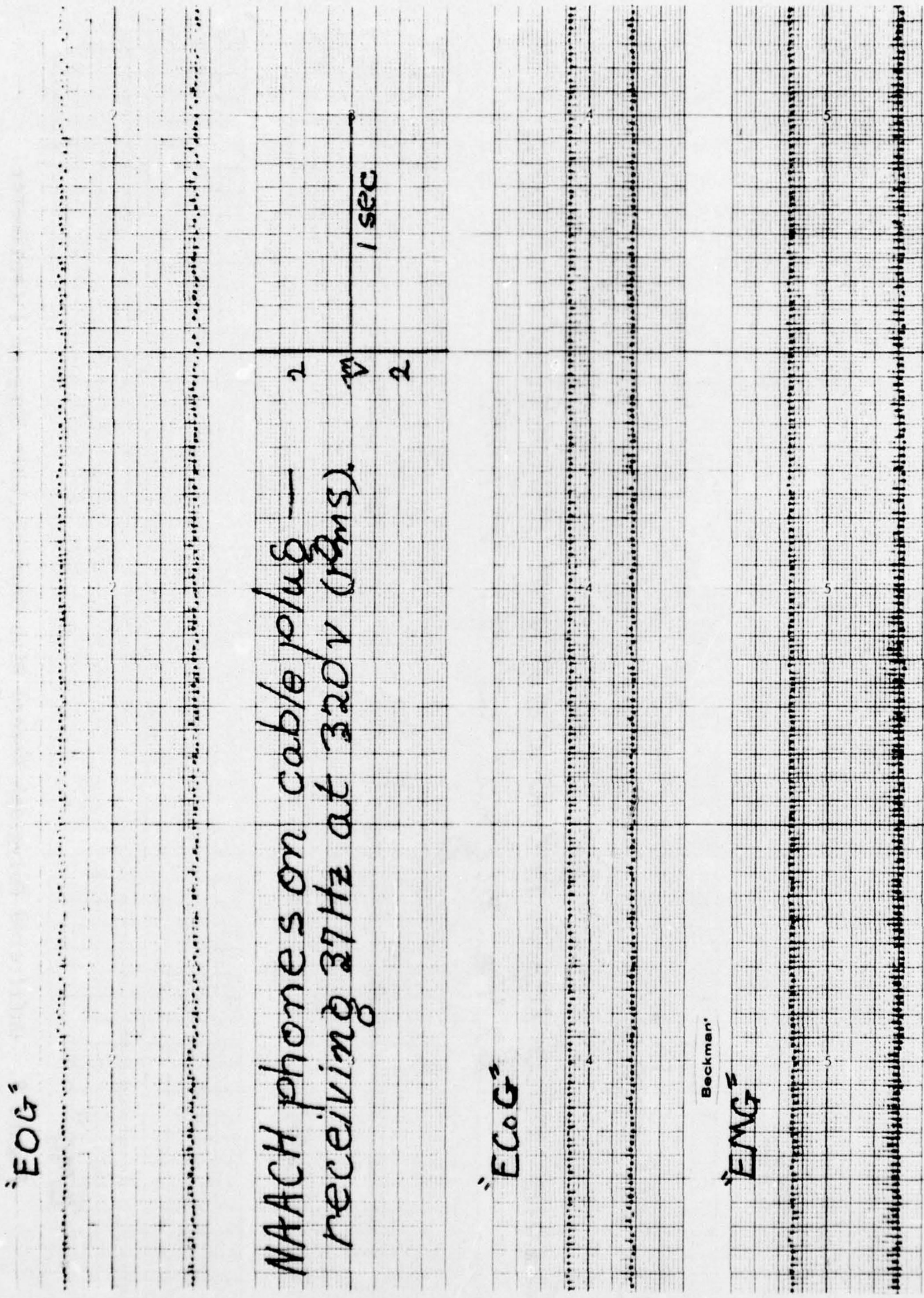

Figure 9. Polygraph Record When the NAACH "Earphones" are Taped to the Cable Plug. (Sensitivity has been reduced to show the entire waves.)

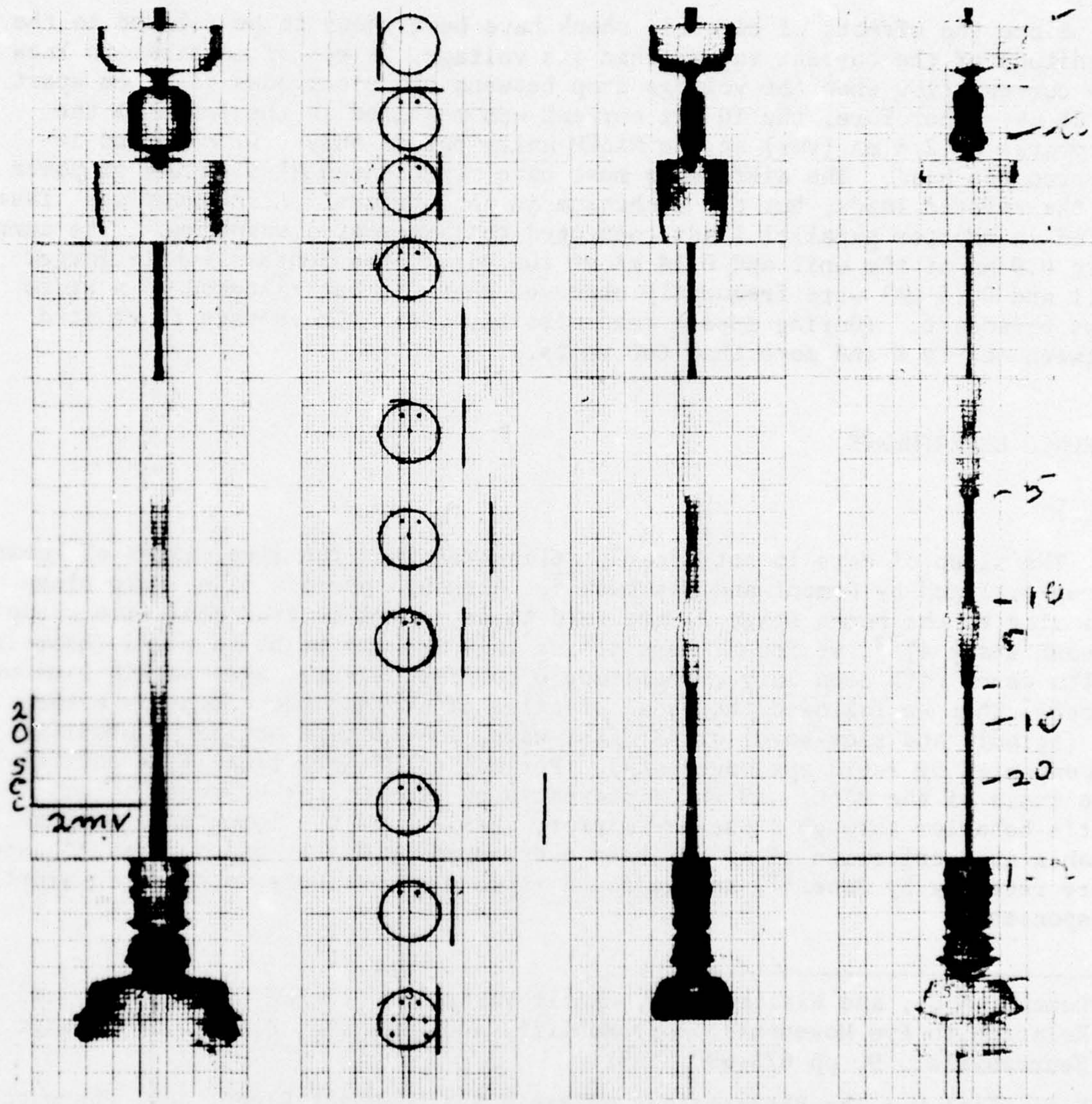

Figure 10. Effect of Spatial Relationship of the "Earphones" to the Cable Plug.

(Only one of the parallel pair of "phones" is shown in each case as a straight line. The plug is represented by a circle within which the dots represent the seven pins. The pin configuration remains the same in every case, even though the pins are not represented in every simulated plug. Individual 37-Hz waves cannot be distinguished because chart speed is only 1 mm/sec. In this figure, the ordinates are seconds, and the abscissae are mV.)

had not passed through the cat, and if the cat had not functioned as a volume conductor, rather than a dielectric; i.e., current flowed radially from the earphones, so that the electrodes and leads to the female plug lay within part of the current path, even though they were outside the cylinder of space between the earphones.

Since the effects of electric shock have been shown to be related to the magnitude of the current rather than its voltage, it was of interest to know the current flow when the voltage drop between two electrodes ca. 1 cm apart is 28 mV. Therefore, the 10-kHz current was measured in the leads to the earphones as 2.8 mA (rms) at the NAACH unit, but as only 0.07 mA where it entered the head. The difference must have represented dissipation of power in the twisted leads, but the mechanism is not obvious. Less power was dissipated in shorter parallel leads connected to larger area earphones. The currents were 0.9 mA at the unit and 0.14 mA at the cat. Transients slightly larger (1.1 and 0.18 mA) were frequently observed when the cat listened to a radio news broadcast. (During speech transmission, the NAACH voltage fluctuated between nearly 0 and more than 600 volts.)

CHRONIC EXPERIMENTS

Sleep

The sleep of cats is not clearly delineated into the five stages of human sleep outlined by Dement and Kleitman[12]. Although periods of spindle sleep (similar to the human stage 2) are said to be separable from slow-wave sleep (human stage 4)[13], we found these stages in some cats to be so mixed (especially delta waves with even larger amplitude 6 to 8/sec waves), even within 1-minute epochs, that we followed the usual practice of scoring the epochs as either QS (spindle and slow-wave) or AS (fast-wave, low-voltage activity, usually accompanied by rapid eye movements). Periods of QS were identified entirely on the basis of the ECoG. AS was differentiated from waking by observations of the cat's behavior through a one-way mirror, inasmuch as the importance of nuchal atonia as a criterion of AS has been questioned by Henley and Morrison[14], and more recently by Jones[15], and we found rapid eye movements to occur in alerting responses.

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[12]Dement, W.C., and Kleitman, N.; Cyclic Variations in EEG During Sleep and Their Relation to Eye Movements, Body Mobility and Dreaming; Electroencephalogr. Clin. Neurophysiol. 9, pp 673-690; 1957.

[13]King, Carl D.; The Pharmacology of Rapid Eye Movement Sleep; Adv. Pharmacol. and Chemotherapy 9; pp 1-91; 1971.

[14]Henley, K., and Morrison, A.R.; A Re-Evaluation of the Effects of Lesions of the Pontine Tegmentum and Locus Coeruleus on Phenomena of Paradoxical Sleep in the Cat; Acta Neurobiol. Exp. 34, pp 215-232; 1974.

[15]Jones, B.E., Harper, S., and Halaris, A.E.; The Effects of Bilateral Locus Coeruleus Lesions on the Sleep-Waking Cycle in the Cat; Neuroscience Abstr.1, p. 1134; 1975.

At the top of table I are shown the results on Cat P, which prompted the series of chronic experiments. This cat was not shielded from environmental noise. Two values are placed in the E_0 boxes because monitoring sessions were run on two consecutive days before exposures began. (The values are percent of total monitoring time.) The mean of E_1, E_2, E_3, and E_4 percents for Q (quiet sleep) was higher than the mean E_0 percent at the 5-percent level of significance (t-test). The results of the later series do not confirm this early result, nor do they suggest an effect on A (active sleep) or on S (total sleep).

Cats 1 and 3 of this series were submitted to 14 days of exposure to acoustical sound before being exposed to NAACH-transmitted sound. C_0 through C_3 of table I represent monitoring sessions before and between exposures to acoustical sound. Cat 5 was exposed to NAACH-transmitted sound before being exposed to acoustical sound*.

Figure 11 displays the QS data in another way that confirms the lack of a trend.

Electrocardiograms

EKG's were recorded before and after exposure to NAACH-transmitted sound. Pre- and post-exposure EKG's were analyzed by a veterinary cardiologist, who found that amplitudes and time limits were within normal limits, and that the experiment did not affect the cardiovascular system as analyzed with this base-apex EKG. However, the possibility was not precluded that subtle cardiac abnormalities might be revealed by additional EKG leads recorded simultaneously on a faster chart in unanesthetized animals trained to submit to the procedure without movement.

Detailed analyses of the EKG's are shown in table II. Three EKG's were recorded from Cat 5, inasmuch as this cat was the only one exposed to the control procedure after the full series of NAACH exposures. Record 5C was recorded following the control series. Cat 6, on the other hand, was exposed only to acoustical sound before losing its skull mount.

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*Six cats were prepared in this series. Unforeseen delays, including illness of the investigator, prevented start of the experiments until 70 days after preparation of the first animal. Due in part to this delay, the first three of these cats lost their skull mounts and ECoG electrodes before the E_2 session, although some previous preparations had kept their skull mounts for several years. They were not replaced because no consistent effect of the exposures had been detected in the animals which did not lose their mounts.

TABLE I. PERCENT TIME IN PHASES OF SLEEP

Cat	Type	C_0	C_1	C_2	C_3	E_0	E_1	E_2	E_3	E_4
	Q					69,77	82	84	82	80
P	A					11, 9	1	14	14	10
	S					80,86	83	98	96	91
	Q	73.9	73.9	57.7	78.2	78.2	55.6	73.2	62.7	
1	A	7.7	12.7	4.2	9.9	7.0	21.1	21.1	4.9	
	S	81.6	86.6	62.0	88.0	85.2	76.7	94.3	67.6	
	Q	78.9	69.0	76.8	76.1	76.1	64.1	75.4	29.6	
3	A	0	3.5	10.5	16.9	0	8.5	12.0	4.2	
	S	78.9	72.5	87.3	93.0	76.1	72.6	87.4	33.8	
	Q					21.8	25.4	40.8	39.4	
5	A					1.4	0	0.7	7.0	
	S					23.2	25.4	41.5	46.4	

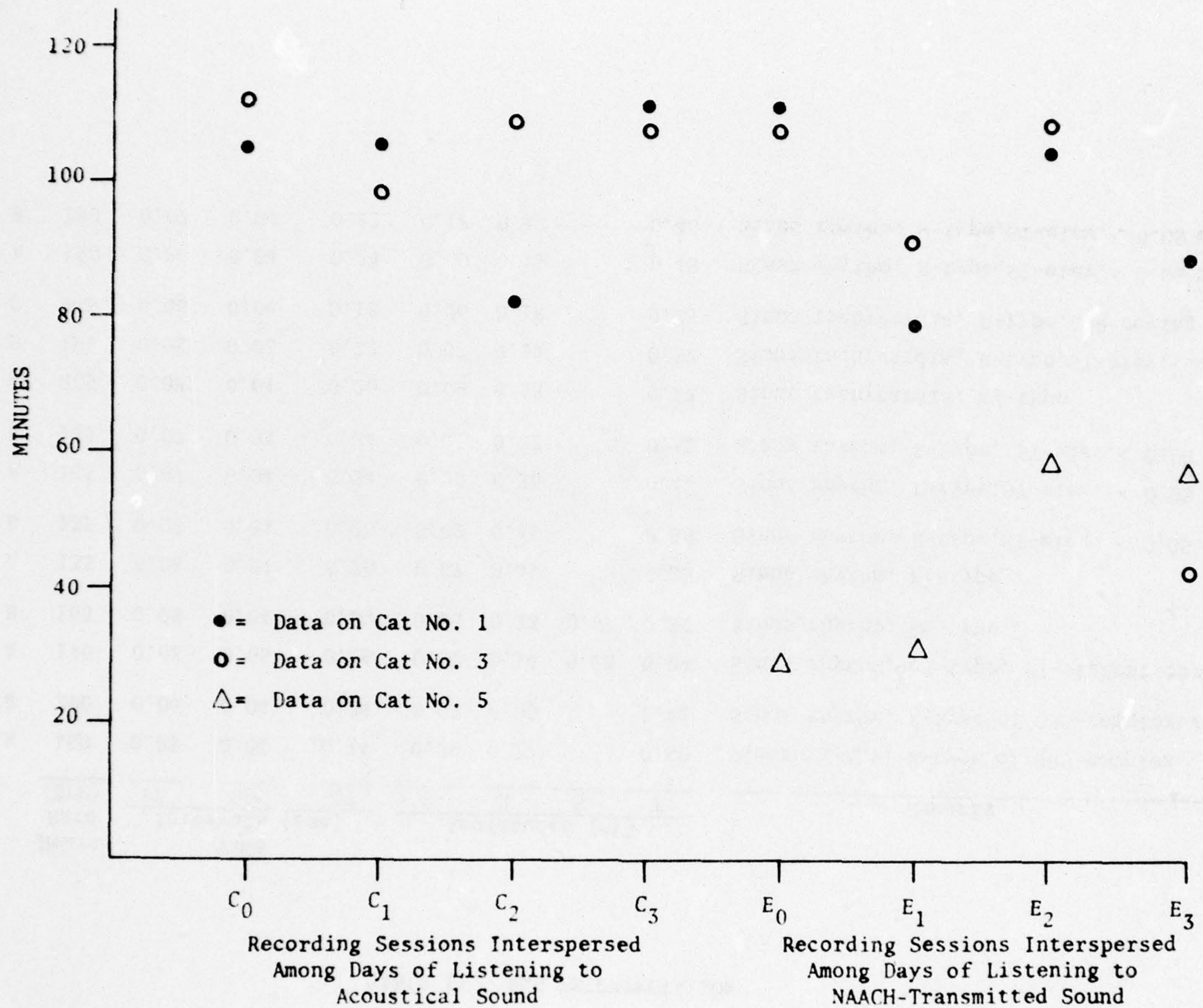

Figure 11. Quiet Sleep of Chronic Cats.
(The ordinates are minutes during 142 minutes of recording.)

TABLE II. EKG INTERPRETATION

Animal		Heart Rate (BPM)	Time Intervals (sec) PR	QRS	QT	Amplitudes (mV) P	R	S	T	Remarks
Cat 1	A	150	0.08	0.04	0.24	0.09	0.27		0.50	Sinus rhythm, R-type of QRS-complex
	B	200	0.06	0.04	0.24	0.07	0.05		0.41	Sinus rhythm, R-type of QRS-complex,very small R
Cat 2	A	140	0.08	0.05	0.26	0.07	0.14	0.23	0.09	Sinus rhythm, rS-type, ST-segment coving
	B	165	0.08	0.04	0.20	0.05	0.23	0.07	0.32	Sinus rhythm, Rs-type
Cat 3	A	135	0.08	0.04	0.26	0.07	0.41		0.36	Sinus rhythm, Rs-type
	B	135	0.08	0.04	0.26	0.09	0.41		0.50	Sinus rhythm, R-type,ST-elev. < 0.05 mV
Cat 4	A	145	0.07	0.04	0.24	0.09	0.36		0.41	Sinus rhythm, R-type,ST-elev. < 0.05 mV
	B	135	0.07	0.03	0.24	0.07	0.32		0.32	Sinus rhythm, R-type, ST-elev.< 0.05 mV
Cat 5	A	205	0.08	0.04	0.20	0.09	0.18		0.27	Sinus tachycardia, Rs-type
	B	195	0.08	0.03	0.22	0.07	0.23		0.32	Sinus tachycardia, R-type,ST-elev.<0.05 mV
	C	245	0.06	0.04	0.18	0.06	0.18		0.23	Sinus tachycardia, R-type, PR-coving
Cat 6	A	150	0.08	0.04	0.24	0.09	0.45		0.45	Sinus rhythm, R-type,ST-elev.< 0.05 mV
	B	180	0.07	0.04	0.22	0.12	0.32		0.45	Sinus rhythm, R-type,ST-elev.< 0.05 mV

DISCUSSION

Assured safety of the human tests requires that current flow through the head be no greater than it was during the cat exposures. Current flow was not continuously measured because the units furnished did not have current measuring capability built in, as had been requested. Instead, the current flow through the head was assumed, on the basis of one set of measurements, to fluctuate continuously during speech reception, with transient peaks under 0.2 mA as long as peak voltages were adjusted so as not to exceed 600 volts. It was assumed that the larger undocumented values may have been due to possible differences in length and configuration of leads, and in some details of internal wiring. This may not have been a valid assumption, inasmuch as the 775-Hz NAACH signal voltage recorded during the spectral sweeps in figures 4 and 5 was more than an order of magnitude lower than recorded previously when the analyzer was tuned to a 1-kHz signal. Part of this discrepancy would be due, of course, to the difference of 225 Hz, and part could be due to error of measurement; e.g., the voltages recorded during a spectral sweep may be too low if the sweep rate is too fast. However, the rate warning light of the analyzer was not glowing. Preliminary attempts to measure a.c. voltage drop across a fixed resistance simulating the cat, using r-c coupling to the wave analyzer to protect it from d.c., revealed many possible sources of error, including the need for continuous balancing of the input impedance to ground. It may be that significant fluctuations of current may be possible in the same unit, at least when the electrodes are placed on different animals or are moved on the same animal.

Consequently, before any human tests can be conducted, the range of current flow received by the cats during the chronic tests should be assessed. It should then be ascertained that current flow in the human tests does not exceed that received by the cats.

After exposure, one of the five cats exhibited a tachycardia that it had not exhibited before exposure. Because this was not a consistent occurrence, there is little reason to assume a causal effect. Nevertheless, it is recommended that pulse rates be counted during each exposure of human subjects, and that clinical EKG's be recorded at least weekly.

Inasmuch as the possibility was not precluded that subtle cardiac abnormalities as a result of exposure might be revealed by simultaneous recording of the EKG from multiple leads without the masking effect of anesthesia, it is considered preferable that this experiment be combined with the assessment of current flow, before tests on human subjects are attempted. Training the cats to submit to the procedure without movement might prove exceedingly difficult. Therefore, it may be more desirable to wait for periods of sleep before recording the EKG.

It has been documented[16] that low-frequency a.c. passing through the vestibular apparatus of human subjects has produced sensations of rotation

[16]Berthold, H.C., and Dzendolet, Ernest; Sensed Movement to Sinusoidal Angular and Electrical Stimulation; Percept.& Motor Skills. 36, pp 23-32; 1973.

and/or tilting. It is conceivable that higher frequency audio signals might also cause disorientation of pilots, possibly with disastrous results. This, and other possible disturbances too subtle to be detected in experimental animals, might interfere with decision-making and concentration. It would be desirable that tests of mental concentration involve separation of auditory material from a sound background, inasmuch as the possibility of deterioration of auditory function has not been ruled out.

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